# MECHANICAL PROPERTIES OF STEERHIDES AND CONSTITUENT COLLAGEN FIBER AGGREGATES*

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## ABSTRACT

Results of measurements of mechanical properties of untanned and tanned samples of six steerhides and of collagen fiber aggregates taken from them are reported and discussed. Hide properties measured included ultimate tenacity, modulus, and ultimate strain in uniaxial tension, stiffness in biaxial tension, burst strength, stitch tear strength, and tongue tear strength. Fiber aggregate properties measured were ultimate tenacity, modulus, and ultimate strain.

Excellent correlation between the properties of hides and fiber aggregates was observed in comparing untanned and tanned samples. Variations from hide to hide and from region to region within a hide were found for the various hide tests, but corresponding variations in fiber aggregate properties were small and probably not significant. Pronounced anisotropic effects were found in those hide tests which were capable of revealing directional phenomena.

## INTRODUCTION

An intensive study of the mechanical properties of collagen fiber aggregates taken from the belly area of a single steerhide has been reported by Dillon *et al.* in a recent paper (1). Techniques and methods of analysis developed in this earlier program have been employed in the work herein described to evaluate the variation of fiber aggregate properties within a hide and from hide to hide, as compared to corresponding variations in hide characteristics—uniaxial and biaxial tensile properties, burst strength, and tear strength.

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## PREPARATION OF HIDE SAMPLES

*Hide treatments.*—The six steerhides employed in these experiments were given the same initial treatment described for Hide A of the earlier work (1), i.e., after removal of the flesh and grain splits from the soaked, limed, and bated steerhides, the remaining center splits were divided into halves by cuts along the backbone. The corresponding half of each hide was tanned with a combination of chromium and vegetable tanning in a regular tannery pack, fatliquored, set out, and dried. The other half of each hide was acidified, dehydrated with acetone, and dried. All hides were tacked to forms and dried under identical conditions. Samples were taken from the tanned halves, pooled, and analyzed. Results of the analysis are given in Table I.

TABLE I

CHEMICAL ANALYSIS OF TANNED HIDES 1–6

| | % |
|---|---|
| Moisture | 12.30 |
| Petroleum ether extract | 6.91 |
| Insoluble ash | 1.59 |
| Hide substance | 50.13 |
| Soluble nontannin | 2.02 |
| Uncombined tannin | 0.83 |
| Combined tannin | 26.22 |
| Total | 100.00 |
| Water-soluble material | 2.85 |
| Total ash | 2.60 |
| Glucose | none |
| $Ca_2O_3$ | 1.52 |
| pH | 3.70 |
| Degree of tannage | 52.30 |
| Ts (Theis meter) | 3 min. boil |

All analysis was done on "as is" basis by ALCA methods.

*Distribution of samples.*—Rectangular blocks were cut from the shoulder, back, and belly of the untanned and tanned sides as shown in Fig. 1. Each of these rectangular regions was divided into areas designated for the various hide and fiber aggregate measurements, as shown in Fig. 2. The fiber aggregates* for each rectangular region were taken from two different locations, No. 26 and No. 28, marked "Fibers" in Fig. 2. It will be noted that samples for hide tests were so chosen that measurements could be made with load applied both parallel and normal to the backbone direction.

*Fiber aggregate tests were made on samples from the belly region of all the hides and from the shoulder and back regions of Hides 1 and 2.

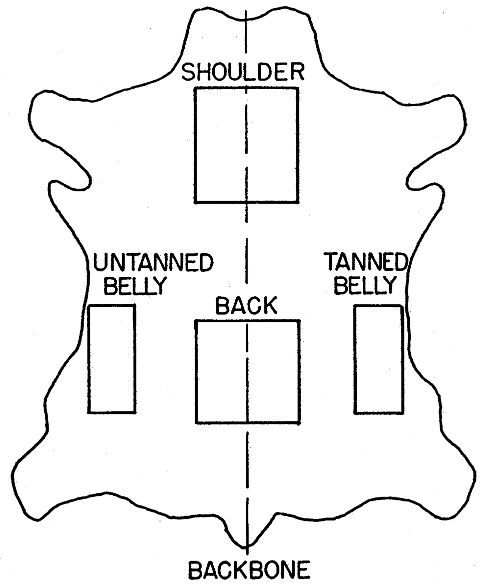


FIGURE 1.—Hide sampling diagram.

## EXPERIMENTAL PROCEDURES

*Measurements of properties of fiber aggregates.*—Measurements of linear density, gage length, and mechanical properties of collagen fiber aggregates were made with the techniques outlined by Dillon *et al.* (1). Ultimate tenacity and modulus were calculated in the manner described in that paper, but ultimate strain was measured from the intersection of the Hookean slope with the strain axis rather than from the origin. This permitted a more precise determination of ultimate strain. Because of the difference in shape of the tenacity-strain curves for the untanned and tanned samples, ultimate strain values calculated in this manner should be compared with caution in estimating the effects of tanning.

*Uniaxial tensile measurements on hide samples.*—The dumbbell strips (Nos. 3, 7, 9, and 22 of Fig. 2) were tested to rupture in serrated grips on the Instron tester with a crosshead speed of 2.54 cm/min., at 65% r.h. and 70°F. The initial gage length was 6.35 cm. After rupture, this section of the sample was cut out and weighed. Ultimate tenacity, modulus, and ultimate strain were calculated in the same units employed for the fiber aggregates, i.e., grams/tex and percent.

*Biaxial tensile measurements of hide samples.*—The square areas (Nos. 11 and 27 of Fig. 2) were tested at 65% r.h. and 70°F. in biaxial strain with equipment developed at Textile Research Institute (2). This equipment

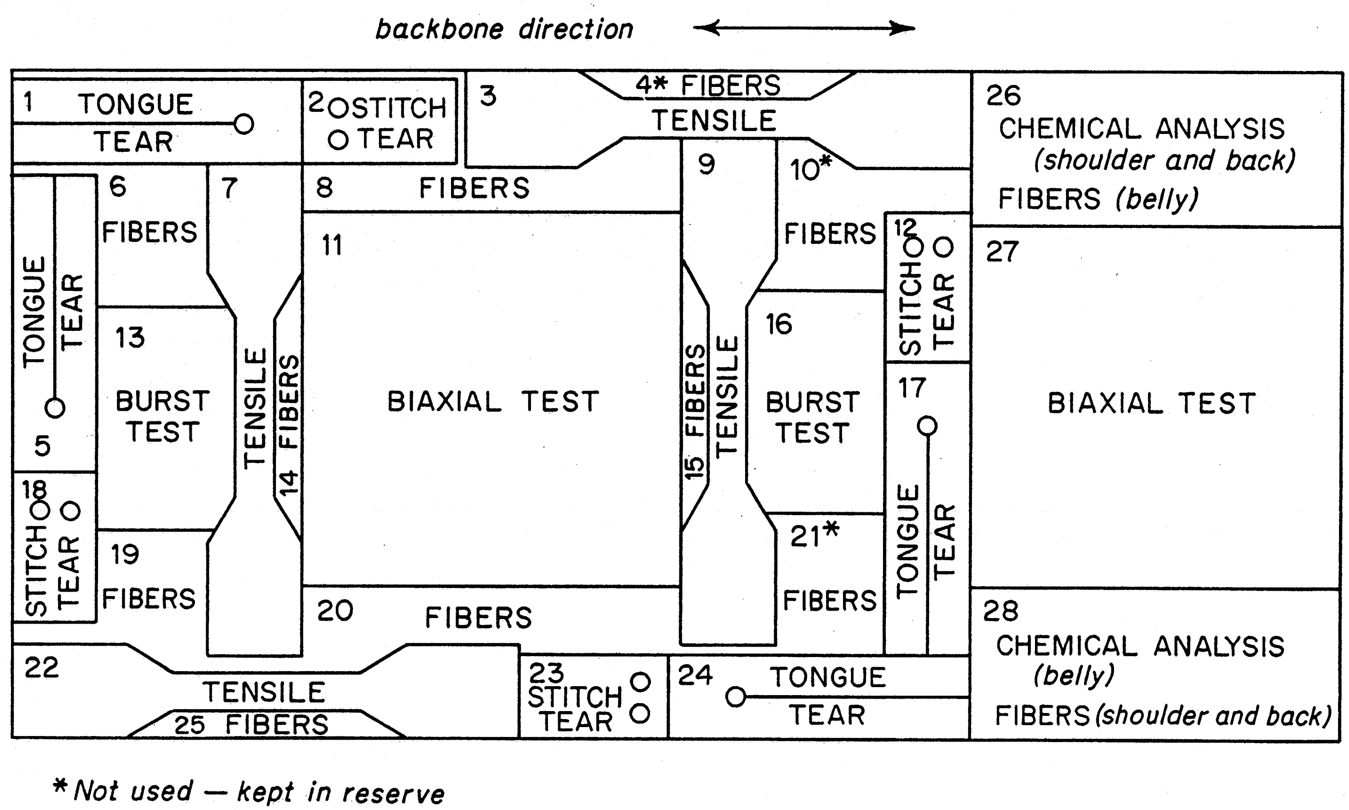


FIGURE 2.—Distribution of test pieces.

consists of a unit, mounted on the crosshead of the Instron tester, which provides simultaneous extension of a "sheet" sample in the vertical and horizontal directions at the same rate (1.27 cm/min.). The loads for the various extensions are measured only in the vertical direction, but by clamping half of the samples with strain axis parallel and the other half normal to a given axis (for example, the backbone direction), load-strain curves corresponding to each of the two orthogonal axes in the plane of a sheet sample can be obtained.

In this work, square test pieces were used with a gage length of 5.08 cm. in each axial direction. The areas between clamps, initially 5.08 x 5.08 cm.$^2$, were cut out and weighed after each test. Since the maximum load attainable with the apparatus was 165 kg., most of the biaxial tests on hide samples could not be carried to rupture. Thus, only values of the "stiffness" (slope of the linear portion of the load-strain curve divided by the weight of the 5.08 x 5.08 cm.$^2$ sample) were calculated.

*Bursting and tear strength tests.*—Burst, stitch tear, and tongue tear tests were carried out in the laboratories of the Eastern Regional Research Laboratory, A.R.S., U.S.D.A., by standard methods of the ALCA at 50% r.h. and 73°F. The test pieces were selected from areas 1, 2, 5, 12, 13, 16, 17, 18, 23, and 24 of Fig. 2. The thickness of each test piece was measured by conventional methods.

Examination of hide samples available for the burst and tear tests revealed appreciable variations in thickness, many of which were not random but which

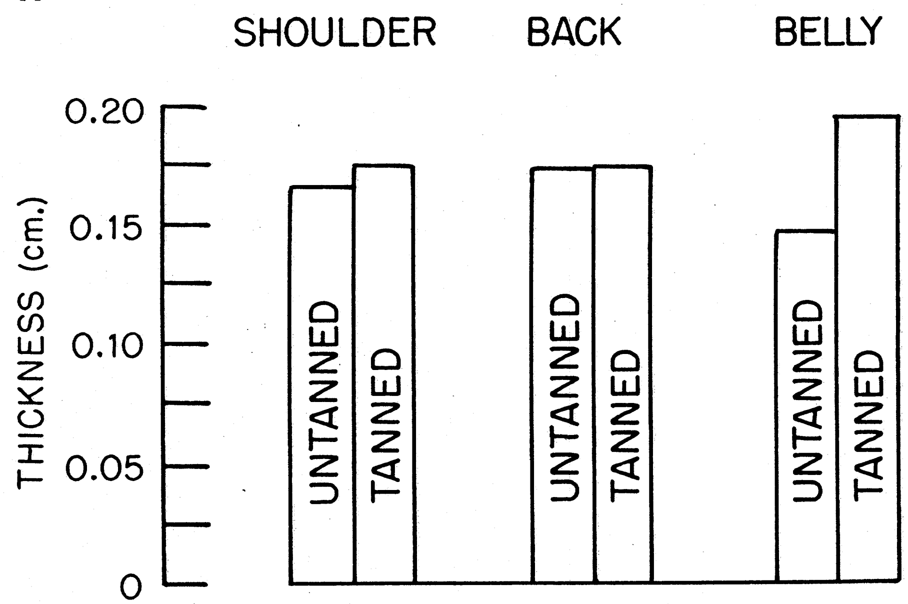


FIGURE 3.–Thickness of various regions of hides.

were related to the region of the hides chosen for tests. For example, tanned samples from the belly area were about 35% thicker than corresponding untanned samples (see bar chart of Fig. 3). Clearly, it was necessary to make a thickness correction. The simplest procedure would be to divide measured loads by thickness, which, since the sample width was constant in any one type of test, would yield values in stress units, i.e., force per unit area. Use of this method did not seem justified, however, since the measured breaking loads did not increase linearly with sample thickness for the tensile tests, and since the dependence of the tear tests upon thickness was theoretically obscure. Hence, the more laborious method of computing "adjusted values" by analysis of covariance was used. This involves the addition of a correction term to the mean and thus does not formally require a change in dimensions from the measured load units (grams or kilograms). In a physical sense, however, this correction method infers a change in dimensions from force with dimensions $(ML/T^2)$ to force/f(A) with dimensions $(ML/T^2/L^n)$, where f(A) is a function of the cross-sectional area A and $n > 1$. Thus, "adjusted loads" of the tables and bar charts presenting the burst and tear strength results are given in units of arbitrary dimensions, expressed as grams (adj.), kg. (adj.), etc.

## STATISTICAL DESIGN OF HIDE EXPERIMENTS

The various experiments involving tests of hide samples were carried out on six hides ($H_1$, $H_2$ --- $H_6$), each split along the backbone into two sides. For each hide, one side was acetone-dehydrated but not tanned (Treatment $T_1$) and the other side was tanned (Treatment $T_2$). After treatment, samples from each side were divided into shoulder, back, and belly regions, denoted as positions $P_1$, $P_2$, $P_3$. Tests parallel and normal to the backbone direction were designated as $D_1$ and $D_2$, respectively.

The statistical design is shown in Fig. 4, using notation familiar to statisticians. For examples, $\sigma^2_E$ = error variance, $\sigma^2_H$ = component of variance among hides, $\sigma^2_T$ = component of variance between treatments, $\sigma^2_{HT}$ = component of variance for the hides × treatments interaction, $\sigma^2_{HTP}$ = component of variance for hides × treatments × positions interaction, etc. To the extent that "treatments" (the tanning and the acetone extraction) of the individual hides were not performed independently, the design is split-plot below H and T. However, since it was not possible to distinguish between the pairs of samples, so as to average properly over the P and D effects, the error within H and T is not available. Therefore, for all testing procedures, it has been assumed that the split-plot character of the design will not result in two error estimates which are distinguishable. The calculated results are shown in the analyses of variance of Tables II, III, and IV.

## TABLE II

UNIAXIAL TENSILE TESTS
ANALYSIS OF VARIANCE

| | | Ultimate Tenacity | | | Modulus | | | Ultimate Strain | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees of Freedom | Mean Squares | F Ratio | Sig. Level % | Mean Squares | F Ratio | Sig. Level % | Mean Squares | F Ratio | Sig. Level % |
| Hides (H) | 5 | 2.9 | 5.4 | 0.1* | 70.6 | 6.8 | 0.1* | 91.2 | 3.2 | 1.0 |
| Treatments (T) | 1 | 28.4 | 67.5 | 0.1* | 51.6 | 7.6 | 5 | 4541.0 | 42.9 | 1 |
| Positions (P) | 2 | 9.0 | 10.8 | 1 | 702.6 | 25.0 | 0.1* | 2016.8 | 48.0 | 0.1* |
| Directions (D) | 1 | 61.7 | 121.8 | 0.1* | 2244.0 | 134.0 | 0.1* | 2917.4 | 243.4 | 0.1* |
| H × T | 5 | 0.4 | 0.8 | — | 6.8 | 0.6 | — | 105.8 | 3.7 | 1 |
| H × P | 10 | 0.8 | 1.5 | 20 | 28.1 | 2.7 | 1 | 42.0 | 1.5 | 20 |
| H × D | 5 | 0.5 | 0.9 | — | 16.7 | 1.6 | 20 | 12.0 | 0.4 | — |
| T × P | 2 | 0.5 | 2.0 | 20 | 62.3 | 10.8 | 1 | 960.3 | 19.2 | 0.1* |
| T × D | 1 | 0.4 | 1.0 | — | 3.9 | 0.6 | — | 63.6 | 2.2 | 20 |
| P × D | 2 | 8.8 | 26.4 | 0.1* | 404.5 | 92.8 | 0.1* | 237.2 | 14.7 | 1 |
| H × T × P | 10 | 0.3 | 0.5 | — | 5.8 | 0.6 | — | 49.9 | 1.7 | 10 |
| H × T × D | 5 | 0.4 | 0.8 | — | 6.4 | 0.6 | — | 29.1 | 1.0 | — |
| H × P × D | 10 | 0.3 | 0.6 | — | 4.4 | 0.4 | — | 16.2 | 0.6 | — |
| T × P × D | 2 | 1.6 | 13.2 | 1 | 3.6 | 0.7 | — | 60.9 | 4.5 | 5 |
| H × T × P × D | 10 | 0.1 | 0.2 | — | 5.0 | 0.5 | — | 13.5 | 0.5 | — |
| Error | 72 | 0.5 | | | 10.3 | | | 28.5 | | |
| Total | 143 | | | | | | | | | |

*Indicates a significance level greater than 0.1%.

| SOURCE OF VARIANCE | DEGREES OF FREEDOM | COMPONENTS OF VARIANCE | | |
|---|---|---|---|---|
| HIDES (H) | 5 | $\sigma_E^2 + 24\sigma_H^2$ | | |
| TREATMENTS (T) | 1 | $\sigma_E^2 + 12\sigma_{HT}^2$ | $+72$ | $\sigma_T^2$ |
| POSITIONS (P) | 2 | $\sigma_E^2 + 8\sigma_{HP}^2$ | $+48$ | $\sigma_P^2$ |
| DIRECTIONS (D) | 1 | $\sigma_E^2 + 12\sigma_{HD}^2$ | $+72$ | $\sigma_D^2$ |
| H x T | 5 | $\sigma_E^2 + 12\sigma_{HT}^2$ | | |
| H x P | 10 | $\sigma_E^2 + 8\sigma_{HP}^2$ | | |
| H x D | 5 | $\sigma_E^2 + 12\sigma_{HD}^2$ | | |
| T x P | 2 | $\sigma_E^2 + 4\sigma_{HTP}^2$ | $+24$ | $\sigma_{TP}^2$ |
| T x D | 1 | $\sigma_E^2 + 6\sigma_{HTD}^2$ | $+36$ | $\sigma_{TD}^2$ |
| P x D | 2 | $\sigma_E^2 + 4\sigma_{HPD}^2$ | $+24$ | $\sigma_{PD}^2$ |
| H x T x P | 10 | $\sigma_E^2 + 4\sigma_{HTP}^2$ | | |
| H x T x D | 5 | $\sigma_E^2 + 6\sigma_{HTD}^2$ | | |
| H x P x D | 10 | $\sigma_E^2 + 4\sigma_{HPD}^2$ | | |
| T x P x D | 2 | $\sigma_E^2 + 2\sigma_{HTPD}^2$ | $+12$ | $\sigma_{TPD}^2$ |
| H x T x P x D | 10 | $\sigma_E^2 + 2\sigma_{HTPD}^2$ | | |
| REPLICATION | 72 | $\sigma_E^2$ | | |
| TOTAL | 143 | | | |

FIGURE 4.—Statistical design of hide experiments.

## TABLE III

### BURST TESTS
### ANALYSIS OF VARIANCE

| Factor | Degrees of Freedom | Mean Squares | F Ratio | Significance Level % |
|---|---|---|---|---|
| Hides (H) | 5 | 4720 | — | — |
| Treatments (T) | 1 | 11160 | 9.1 | 3.1 |
| Positions (P) | 2 | 17562 | 13.7 | 0.1* |
| H × T | 5 | 1233 | — | — |
| H × P | 10 | 1287 | — | — |
| T × P | 2 | 1146 | 1.4 | — |
| H × T × P | 10 | 829 | — | — |
| Error | 108† | 8404 | — | — |
| Total | 143 | | | |

*Indicates significance level greater than 0.1%.
†There are only 108 degrees of freedom for the burst tests since the Direction effect cannot be tested (4 replications at each position of each side in each hide).

## TABLE IV

### TEAR TESTS
### ANALYSIS OF VARIANCE

| | | Tongue Tear Tests | | | | | | Stitch Tear Tests | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Breaking Load | | | First Tear | | | Tear Strength | | |
| | Degrees of Freedom | Mean Squares | F Ratio | Sig. Level % | Mean Squares | F Ratio | Sig. Level % | Mean Squares | F Ratio | Sig. Level % |
| Hides (H) | 5 | 155 | 11.9 | 0.1* | 97 | 8.9 | 0.1* | 854 | 4.9 | 0.1* |
| Treatments (T) | 1 | 1199 | 41.3 | 1 | 183 | 8.6 | 5 | 14281 | 610.6 | 0.1* |
| Positions (P) | 2 | 1020 | 56.7 | 0.1* | 89 | 5.9 | 5 | 2438 | 6.2 | 5 |
| Directions (D) | 1 | 253 | 10.5 | 5 | 70 | 6.5 | 5 | 8295 | 16.5 | — |
| H × T | 5 | 29 | 2.23 | — | 21 | 1.9 | — | 23 | — | — |
| H × P | 10 | 18 | 1.38 | — | 15 | 1.4 | — | 392 | 2.3 | 5 |
| H × D | 5 | 24 | 1.85 | — | 11 | 1.6 | — | 502 | 2.9 | 5 |
| T × P | 2 | 88 | 3.8 | — | 25 | — | — | 785 | 2.0 | — |
| T × D | 1 | 29 | 2.42 | — | 61 | 9.5 | 5 | 878 | 2.7 | — |
| P × D | 2 | 109 | 54.5 | 0.1* | 22 | 5.2 | 5 | 129 | — | — |
| H × T × P | 10 | 23 | 1.77 | — | 28 | 2.5 | 1 | 386 | 2.2 | 5 |
| H × T × D | 5 | 12 | — | — | 6 | — | — | 329 | 1.9 | — |
| H × P × D | 10 | 2 | — | — | 4 | — | — | 141 | — | — |
| T × P × D | 2 | 0 | — | — | 55 | 7.4 | 1 | 259 | 1.5 | — |
| H × T × P × D | 10 | 31 | 2.4 | 5 | 7 | — | — | 0 | — | — |
| Error | 72 | 13 | | | 11 | | | 174 | | |
| Total | 143 | | | | | | | | | |

*Indicates significance level greater than 0.1%.

## VARIATION OF FIBER AGGREGATE PROPERTIES WITHIN A HIDE

Values of mean gage length and mechanical properties of fiber aggregates taken from the shoulder, back, and belly areas of Hide 2 are given in Table V. Unfortunately, it proved difficult to extract fibers of the desired 1-cm. gage length from the back area; the mean gage length (0.64 cm.) is considerably lower than those for the aggregates from the shoulder and belly areas (0.99 and 1.23 cm.). On the basis of previous work on the effects of varying gage length (1), a significantly higher ultimate strain and a lower modulus would be predicted for the shorter aggregates. This is exactly what was observed. Hence, as far as the data of Table V are concerned, it must be

### TABLE V

TENSILE PROPERTIES OF FIBER AGGREGATES

*(Samples taken from shoulder, back, and belly areas of Hide 2, tanned; tested at 65% r.h. and 70°F.)*

*(49 tests for each mean)*

| Property | Area | Mean | C.V. % |
|---|---|---|---|
| Gage length, cm. | Shoulder | 0.99 | 18 |
| | Back | 0.64 | 22 |
| | Belly | 1.23 | 28 |
| Ultimate tenacity, g/tex | Shoulder | 22.7 | 18 |
| | Back | 21.6 | 22 |
| | Belly | 21.1 | 19 |
| Modulus, g/tex | Shoulder | 135. | 15 |
| | Back | 111. | 21 |
| | Belly | 140. | 15 |
| Ultimate strain,*% | Shoulder | 22.1 | 18 |
| | Back | 27.4 | 20 |
| | Belly | 21.1 | 21 |

*Values of ultimate strain measured from intersection of the Hookean slope with strain axis.

acknowledged that observed differences in ultimate tenacity, modulus, and ultimate strain, at 65% r.h. and 70°F., may not reflect real variations in the properties of fiber aggregates taken from the shoulder, back, and belly areas of the tanned portion of Hide 2. Tenacity-strain curves for aggregates from the shoulder and belly areas are given in Fig. 5.

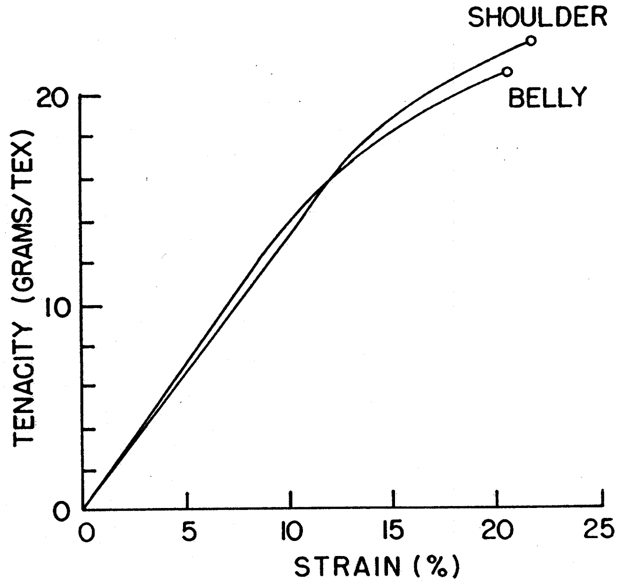


FIGURE 5.—Tenacity-strain curves for the shoulder and belly regions of Hide 2; 65% r.h., 70°F.

## VARIATION OF FIBER AGGREGATE PROPERTIES FROM HIDE TO HIDE

Tensile properties measured at 65% r.h. and 70°F., linear density, and mean gage length of fiber aggregates taken from belly areas of the six hides, untanned and tanned, are given in Table VI. No significant differences in the mechanical properties—ultimate tenacity, modulus, and ultimate strain—for Hides 1–6 were evident. In fact, considering the complex structure of collagen fiber aggregates and the rather large coefficients of variation, the measured values of the properties were remarkably uniform for the six hides. Fortunately, the mean gage length was nearly the same for all the tests, except for that of the tanned sample of Hide 4 (1.33 cm.), which was significantly higher than the gage lengths of other samples. In accord with previous studies of the effects of gage length (1), this sample exhibited a relatively low ultimate strain.

Assuming that there was no significant variation of the properties among hides (as indicated in Table VI), it is apparent that tanning significantly reduced the "dry" fiber aggregate strength (ultimate tenacity). This is in accord with previous results (1). The modulus was changed very little, if at all, by tanning. Comparison of the ultimate strain values for the untanned and tanned samples is not generally permissible, as explained earlier in this paper. However, conversion of these ultimate strain values to "true ultimate

## TABLE VI

### TENSILE PROPERTIES OF FIBER AGGREGATES

*(Belly areas of six hides, tested at 65% r.h. and 70°F.)*

*(51–56 tests for each mean)*

| Property | Hide | Untanned | | Tanned | |
|---|---|---|---|---|---|
| | | Mean | % C.V. | Mean | % C.V. |
| Gage length, cm. | 1 | 1.16 | 27 | 1.00 | 20 |
| | 2 | 1.11 | 22 | 1.23 | 21 |
| | 3 | 1.16 | 18 | 1.02 | 20 |
| | 4 | 1.03 | 26 | 1.33 | 21 |
| | 5 | 0.97 | 20 | 1.04 | 16 |
| | 6 | 1.02 | 21 | 1.05 | 16 |
| | Av. | 1.08 | | 1.11 | |
| Linear density, tex | 1 | 5.30 | 39 | 6.35 | 29 |
| | 2 | 6.26 | 25 | 9.57 | 33 |
| | 3 | 4.66 | 32 | 7.38 | 33 |
| | 4 | 6.13 | 35 | 9.17 | 34 |
| | 5 | 5.73 | 41 | 8.38 | 31 |
| | 6 | 6.60 | 46 | 7.88 | 39 |
| | Av. | 5.78 | | 8.12 | |
| Ultimate tenacity, g/tex | 1 | 28.5 | 23 | 21.4 | 19 |
| | 2 | 30.1 | 23 | 21.1 | 18 |
| | 3 | 35.2 | 20 | 25.3 | 18 |
| | 4 | 29.1 | 22 | 23.7 | 20 |
| | 5 | 33.0 | 27 | 24.0 | 21 |
| | 6 | 32.2 | 23 | 22.4 | 25 |
| | Av. | 31.4 | | 23.0 | |
| Modulus, g/tex | 1 | 145 | 20 | 119 | 11 |
| | 2 | 148 | 18 | 140 | 9 |
| | 3 | 166 | 15 | 161 | 8 |
| | 4 | 141 | 20 | 157 | 6 |
| | 5 | 147 | 19 | 142 | 10 |
| | 6 | 148 | 21 | 132 | 11 |
| | Av. | 149 | | 142 | |
| Ultimate strain,*% | 1 | 26.8 | 18 | 22.3 | 20 |
| | 2 | 26.3 | 19 | 22.2 | 21 |
| | 3 | 26.9 | 20 | 22.5 | 19 |
| | 4 | 27.1 | 19 | 20.1 | 18 |
| | 5 | 30.1 | 21 | 23.4 | 20 |
| | 6 | 29.4 | 19 | 25.6 | 19 |
| | Av. | 27.8 | | 22.7 | |

*Values of ultimate strain measured from intersection of the Hookean slope with strain axis.

strains" measured from the tenacity-strain origin would increase the values for the untanned aggregates more than the values for the tanned. Hence, it may be concluded that the decrease in ultimate strain due to tanning, shown in Table VI, was real.

Another hide-to-hide comparison of properties is given in Table VII. Here back areas of Hides 1 and 2 were found to yield essentially the same

TABLE VII

TENSILE PROPERTIES OF FIBER AGGREGATES

(*Samples taken from back areas of tanned hides 1 and 2*)

(*Tested at 65% r.h. and 70°F.; 50–51 tests for each mean*)

| Property | Hide | Mean | C.V. % |
|---|---|---|---|
| Gage length, cm. | 1 | 0.74 | 19 |
| | 2 | 0.64 | 20 |
| Linear density, tex | 1 | 5.60 | 31 |
| | 2 | 7.95 | 31 |
| Ultimate tenacity, g/tex | 1 | 23.8 | 21 |
| | 2 | 21.9 | 21 |
| Modulus, g/tex | 1 | 130.1 | 17 |
| | 2 | 111.0 | 20 |
| Ultimate strain,* % | 1 | 26.3 | 20 |
| | 2 | 27.4 | 20 |

*Values of ultimate strain measured from intersection of Hookean slope with strain axis.

values of ultimate tenacity, modulus, and ultimate strain. Small observed variations in modulus and ultimate strain (probably not significant) were consistent with predictions of previous work (1).

## UNIAXIAL TENSILE PROPERTIES OF HIDE SAMPLES

The results of measurements made with dumbbell strips on the Instron tester are given in Table VIII. Examination of the data for the individual hides and the average values for each hide region (ignoring hide-to-hide variations which, according to the analysis of variance of Table II, are significant) yielded the following conclusions: (*a*) The tanned hide samples were weaker (lower ultimate tenacity) and less extensible (lower ultimate strain) than the untanned hide samples. (*b*) Modulus was not changed

## TABLE VIII

UNIAXIAL TENSILE PROPERTIES OF STEERHIDES

*(Dumbbell strips tested with Instron machine at 65% r.h. and 70°F.)*

| Hide Area | No. | Ultimate Tenacity grams/tex | | Modulus grams/tex | | Ultimate Strain % | |
|---|---|---|---|---|---|---|---|
| | | Direction of Load in Respect to Backbone | | | | | |
| | | Parallel | Normal | Parallel | Normal | Parallel | Normal |
| | | *UNTANNED SAMPLES* | | | | | |
| Shoulder | 1 | 4.18 | 3.27 | 16.7 | 11.6 | 29.1 | 34.4 |
| | 2 | 5.03 | 2.64 | 18.8 | 8.78 | 35.2 | 36.1 |
| | 3 | 3.20 | 2.73 | 8.89 | 6.52 | 40.8 | 51.9 |
| | 4 | 4.41 | 3.32 | 16.3 | 9.08 | 33.2 | 43.8 |
| | 5 | 4.24 | 2.54 | 14.2 | 5.93 | 37.2 | 52.8 |
| | 6 | 4.20 | 3.11 | 11.3 | 6.62 | 44.0 | 53.2 |
| Hide Av. | | 4.21 | 2.93 | 14.4 | 8.09 | 36.6 | 45.4 |
| Isotropic Av. | | 3.57 | | 11.2 | | 40.8 | |
| Back | 1 | 3.86 | 2.38 | 9.53 | 5.15 | 49.2 | 52.08 |
| | 2 | 3.81 | 2.41 | 9.14 | 5.43 | 47.5 | 55.3 |
| | 3 | 3.12 | 2.34 | 7.49 | 5.53 | 52.5 | 55.4 |
| | 4 | 4.09 | 3.24 | 10.45 | 7.65 | 48.0 | 50.8 |
| | 5 | 2.97 | 1.97 | 6.94 | 3.73 | 55.1 | 60.0 |
| | 6 | 2.68 | 2.44 | 8.40 | 6.17 | 40.3 | 47.5 |
| Hide Av. | | 3.42 | 2.46 | 8.66 | 5.61 | 48.8 | 53.6 |
| Isotropic Av. | | 2.94 | | 7.14 | | 51.2 | |
| Belly | 1 | 5.66 | 4.17 | 29.7 | 16.9 | 24.2 | 30.4 |
| | 2 | 4.92 | 2.54 | 23.4 | 9.06 | 26.4 | 35.6 |
| | 3 | 3.86 | 2.37 | 18.6 | 8.07 | 26.4 | 35.9 |
| | 4 | 4.61 | 2.11 | 22.5 | 7.34 | 25.6 | 38.6 |
| | 5 | 4.21 | 1.97 | 17.5 | 6.68 | 30.9 | 42.6 |
| | 6 | 4.98 | 3.21 | 27.8 | 11.9 | 24.1 | 35.8 |
| Hide Av. | | 4.71 | 2.73 | 23.2 | 9.89 | 26.3 | 36.5 |
| Isotropic Av. | | 3.72 | | 16.6 | | 31.4 | |
| Grand Iso. Av. | | 3.41 | | 11.6 | | 41.1 | |
| | | *TANNED SAMPLES* | | | | | |
| Shoulder | 1 | 3.04 | 2.44 | 17.4 | 8.57 | 18.8 | 32.5 |
| | 2 | 2.61 | 2.08 | 15.8 | 9.71 | 18.6 | 23.2 |
| | 3 | 2.19 | 2.36 | 8.96 | 9.87 | 27.5 | 25.7 |
| | 4 | 2.76 | 2.79 | 14.7 | 9.72 | 21.6 | 33.6 |
| | 5 | 2.48 | 1.72 | 13.9 | 6.79 | 21.2 | 26.9 |
| | 6 | 3.45 | 1.55 | 18.4 | 5.91 | 20.8 | 27.8 |
| Hide Av. | | 2.74 | 2.15 | 14.8 | 8.43 | 21.4 | 28.3 |
| Isotropic Av. | | 2.46 | | 11.6 | | 24.9 | |

TABLE VIII (*Continued*)

| Hide Area | No. | Ultimate Tenacity grams/tex | | Modulus grams/tex | | Ultimate Strain % | |
|---|---|---|---|---|---|---|---|
| | | Direction of Load in Respect to Backbone | | | | | |
| | | Parallel | Normal | Parallel | Normal | Parallel | Normal |
| | | *TANNED SAMPLES* | | | | | |
| Back | 1 | 2.88 | 2.08 | 10.2 | 5.47 | 31.9 | 42.7 |
| | 2 | 2.32 | 1.55 | 8.67 | 5.28 | 29.4 | 33.7 |
| | 3 | 1.89 | 1.65 | 6.64 | 5.43 | 29.8 | 32.6 |
| | 4 | 2.48 | 2.36 | 10.4 | 6.53 | 36.4 | 40.2 |
| | 5 | 1.93 | 1.77 | 7.10 | 5.02 | 30.0 | 38.4 |
| | 6 | 2.21 | 1.87 | 7.59 | 4.98 | 33.4 | 41.5 |
| Hide Av. | | 2.28 | 1.88 | 8.44 | 5.45 | 31.8 | 38.2 |
| Isotropic Av. | | 2.08 | | 6.95 | | 35.0 | |
| Belly | 1 | 5.20 | 2.85 | 25.4 | 9.27 | 21.1 | 37.1 |
| | 2 | 3.48 | 1.47 | 19.2 | 4.59 | 18.5 | 37.5 |
| | 3 | 4.41 | 2.28 | 19.5 | 6.32 | 23.6 | 40.8 |
| | 4 | 4.26 | 1.63 | 15.8 | 3.80 | 21.5 | 47.9 |
| | 5 | 4.08 | 0.74 | 19.5 | 2.23 | 24.0 | 35.5 |
| | 6 | 4.41 | 1.57 | 22.9 | 4.50 | 21.6 | 37.6 |
| Hide Av. | | 4.31 | 1.76 | 20.4 | 5.12 | 21.7 | 39.4 |
| Isotropic Av. | | 3.03 | | 12.8 | | 30.6 | |
| Grand Iso. Av. | | 2.52 | | 10.5 | | 30.2 | |

significantly by tanning except for the belly region tested normal to the backbone, in which case the modulus dropped considerably with tanning. (*c*) For the areas studied, tests made with load parallel to the backbone gave higher strength (ultimate tenacity), higher modulus, and lower extensibility (ultimate strain) compared to values obtained with load normal to the backbone. These effects were magnified in the more anisotropic belly region. One must remember that the directions chosen for the present test pieces may not show the maximum anisotropic differences. Maeser (3) has demonstrated that the axis and degree of anisotropy vary from one region of a hide to the next. (*d*) Samples from the shoulder region were stronger, stiffer, and less extensible than samples from the back region. (*e*) The effects of tanning were consistent for the hide averages and indeed for most of the individual hides, except for the belly region. The bar chart of Fig. 6 has been plotted with the properties averaged over the six hides to aid in the interpretation of Table VIII.

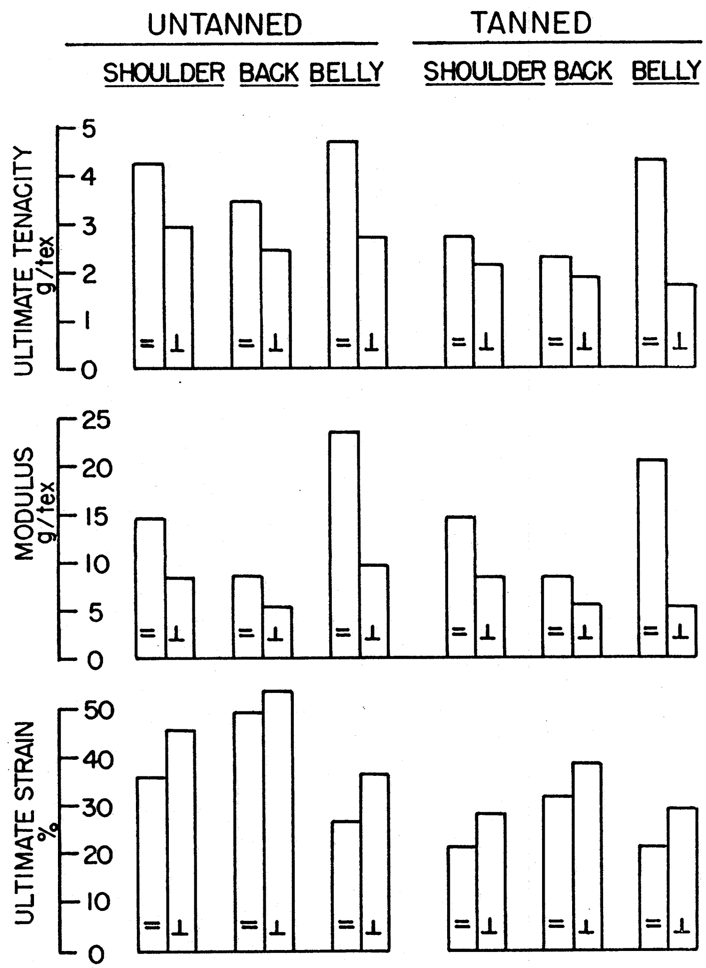


FIGURE 6.—Uniaxial tensile properties averaged over Hides 1–6.

## BIAXIAL TENSILE PROPERTIES OF HIDE SAMPLES

Stiffness values obtained in the biaxial tensile tests, for untanned and tanned samples of the shoulder, back, and belly regions, averaged over the observed values for the six hides, are shown in Table IX. As noted earlier, biaxial stiffness is defined as the slope of the load-strain curve divided by the weight of the biaxially extended portion of the sample. Thus, biaxial stiffness is comparable to modulus as measured for fiber aggregates and in the uniaxial hide tests but is not identical with modulus in dimensions.

The results of Table IX yielded one clear conclusion, that the orientation of the fiber aggregates in the backbone direction is much the highest in the

# TABLE IX

## BIAXIAL TENSILE PROPERTIES OF STEERHIDES

*(65% r.h.; 70°F)*

| Hide Area | Biaxial Stiffness (kg/g for unit strain) | | | |
|---|---|---|---|---|
| | Parallel to Backbone | | Normal to Backbone | |
| | Untanned | Tanned | Untanned | Tanned |
| Shoulder | 116 | 123 | 99 | 82 |
| Back | 62 | 73 | 66 | 74 |
| Belly | 213 | 227 | 123 | 50 |

Note: Each stiffness figure is the average for 2 samples from each of 6 hides.

# TABLE X

## BURST STRENGTH OF STEERHIDES

*(Tested at 50% r.h. and 73°F.; 4 tests for each mean)*

| Hide Area | Hide No. | Mean Burst Strength kg.(adj.) | |
|---|---|---|---|
| | | Untanned | Tanned |
| Shoulder | 1 | 74 | 58 |
| | 2 | 68 | 67 |
| | 3 | 65 | 59 |
| | 4 | 87 | 71 |
| | 5 | 68 | 58 |
| | 6 | 79 | 64 |
| | Av. | 73 | 63 |
| Back | 1 | 73 | 55 |
| | 2 | 65 | 51 |
| | 3 | 64 | 47 |
| | 4 | 77 | 60 |
| | 5 | 49 | 52 |
| | 6 | 54 | 54 |
| | Av. | 64 | 53 |
| Belly | 1 | 95 | 78 |
| | 2 | 71 | 72 |
| | 3 | 70 | 77 |
| | 4 | 77 | 78 |
| | 5 | 54 | 65 |
| | 6 | 95 | 75 |
| | Av. | 77 | 74 |
| Grand Average | | 71 | 63 |

belly region. In this respect, the biaxial tests show some promise for studies of hide anisotropy.

The effects of tanning are not clearly revealed in Table IX. However, the relatively low modulus of the back region found for the uniaxial tests was confirmed, as was the greater anisotropy of the belly region.

### BURST STRENGTH

The burst test, in which a spherical indenter is applied to a hide sample at a constant rate of motion, is designed to give an average of rupture properties over the initial plane of the sample. Thus, it was not surprising to find for the relatively isotropic regions, shoulder and back, that the burst strength was reduced by tanning (Table X and Fig. 7). In other respects, results of this test correlated with other measurements which would be considered comparable, for example, the isotropic averages of ultimate tenacity in the uniaxial tests.

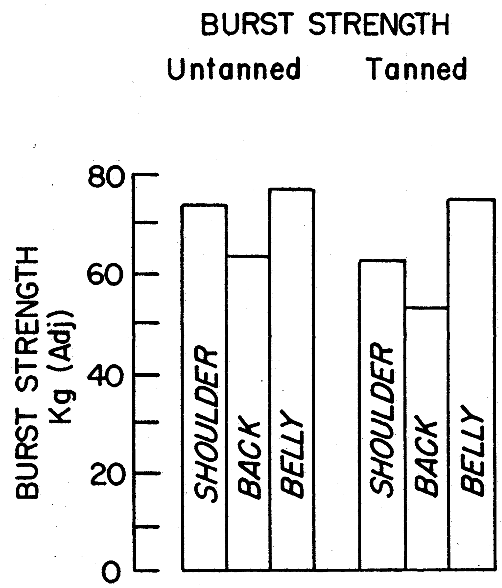


FIGURE 7.—Burst strength averaged over backbone and normal-to-backbone directions of Hides 1–6.

### TEAR STRENGTH

The stitch tear data of Table XI show small anisotropic effects for all regions of the hides, untanned and tanned. This test involves pulling a previously drilled hide sample against a rigid rod inserted in the drilled hole. Thus, the test might be considered to impart a "splitting force" in a direction normal to that of the applied tensile load. Hence, it might be expected that

## TABLE XI

STITCH TEAR STRENGTH OF STEERHIDES

*(Tested at 50% r.h. and 73°F.; 2 tests for each mean)*

| Hide Area | Hide No. | Mean Stitch Tear Strength kg. (adj.) Untanned | | Tanned | |
|---|---|---|---|---|---|
| | | Direction of Test in Respect to Backbone | | | |
| | | Parallel | Normal | Parallel | Normal |
| Shoulder | 1 | 25 | 36 | 30 | 43 |
| | 2 | 19 | 23 | 25 | 43 |
| | 3 | 25 | 24 | 33 | 38 |
| | 4 | 27 | 23 | 36 | 42 |
| | 5 | 20 | 29 | 25 | 32 |
| | 6 | 25 | 30 | 16 | 48 |
| | Av. | 23 | 27 | 27 | 41 |
| Back | 1 | 19 | 27 | 31 | 39 |
| | 2 | 20 | 29 | 22 | 27 |
| | 3 | 20 | 16 | 24 | 26 |
| | 4 | 27 | 27 | 31 | 40 |
| | 5 | 15 | 20 | 19 | 23 |
| | 6 | 20 | 23 | 23 | 35 |
| | Av. | 20 | 24 | 25 | 32 |
| Belly | 1 | 28 | 29 | 45 | 47 |
| | 2 | 22 | 19 | 30 | 37 |
| | 3 | 21 | 24 | 40 | 36 |
| | 4 | 16 | 23 | 31 | 36 |
| | 5 | 20 | 35 | 36 | 47 |
| | 6 | 25 | 44 | 27 | 44 |
| | Av. | 22 | 29 | 35 | 41 |
| Grand Averages | | 24 | | 34 | |

the stitch tear strength would be greater with load applied in a direction normal to the backbone. This is precisely what was observed. In the bar chart of Fig. 8, anisotropic effects were eliminated by averaging tear strengths measured with load parallel and normal to the backbone direction. Here it is seen that tanning increased the stitch tear strength. The effect was greater in the more anisotropic belly region, as might be anticipated.

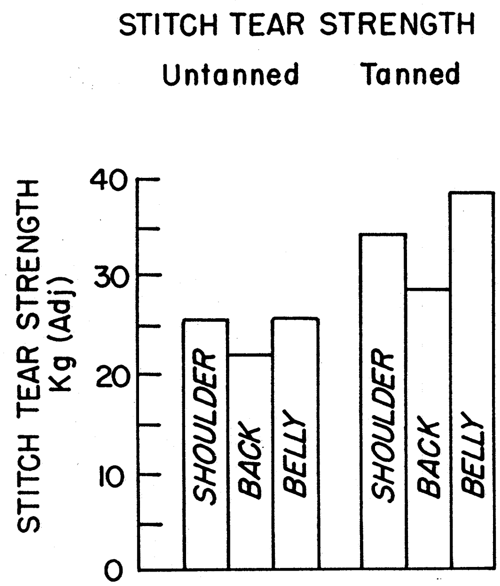


FIGURE 8.—Stitch tear strength averaged over backbone and normal-to-backbone directions of Hides 1–6.

The tongue tear results, given in Table XII, correlated very well with those of the stitch tear tests. The tongue tear tests were more sensitive to variations in sample thickness, however. Qualitatively, the tongue tear and stitch tear values agreed in yielding higher values with load applied normal to the backbone direction, in contrast to the results of the uniaxial tensile tests in which the ultimate tenacity was found to be higher in the backbone direction.

### CORRELATION OF FIBER AGGREGATE AND HIDE PROPERTIES

One of the principal objectives of this work was to determine to what extent the mechanical properties of untanned and tanned hides are influenced by the properties of the constituent fiber aggregates. It was clear at the outset that the mechanical behavior of a hide or a leather must be governed by at least two major components: (*a*) the mechanical properties of the fiber aggregates, and (*b*) interaggregate reactions. Thus, recognizing that fiber aggregate properties can be only a part of the story of hide and leather performance, little would be accomplished by an over-all statistical correlation of the properties of fiber aggregates with those of the hides. Rather, it seemed necessary to develop a series of correlations, each based upon a specific independent parameter. This section is organized in accord with this conclusion.

## TABLE XII

### TONGUE TEAR TESTS ON STEERHIDES

*(Tested at 50% r.h. and 73°F.; 2 tests for each mean)*

| | | Breaking Load kg.(adj.) | | | | First Tear kg.(adj.) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Untanned | | Tanned | | Untanned | | Tanned | |
| | | Direction of Test in Respect to Backbone | | | | | | | |
| Hide Area | Hide No. | Para. | Norm. | Para. | Norm. | Para. | Norm. | Para. | Norm. |
| Shoulder | 1 | 7.4 | 9.7 | 8.8 | 11.6 | 5.1 | 4.4 | 7.4 | 6.1 |
| | 2 | 7.7 | 8.4 | 12.7 | 17.1 | 4.7 | 4.6 | 5.9 | 5.9 |
| | 3 | 4.8 | 6.9 | 8.1 | 10.0 | 2.6 | 3.6 | 5.8 | 5.6 |
| | 4 | 5.6 | 10.1 | 8.9 | 16.6 | 3.0 | 5.2 | 7.3 | 8.2 |
| | 5 | 6.1 | 7.5 | 7.6 | 7.8 | 3.0 | 3.7 | 4.0 | 3.7 |
| | 6 | 6.6 | 7.7 | 10.7 | 15.0 | 4.8 | 4.9 | 5.5 | 5.4 |
| | Av. | 6.4 | 8.4 | 9.5 | 13.0 | 3.9 | 4.6 | 6.0 | 5.8 |
| Back | 1 | 7.3 | 6.7 | 6.3 | 6.9 | 6.1 | 4.7 | 5.4 | 5.1 |
| | 2 | 5.8 | 6.3 | 7.7 | 7.1 | 5.3 | 5.7 | 3.5 | 3.8 |
| | 3 | 6.0 | 5.2 | 5.2 | 7.5 | 3.4 | 2.5 | 3.2 | 4.7 |
| | 4 | 5.9 | 5.9 | 7.3 | 10.1 | 3.9 | 3.6 | 4.0 | 5.8 |
| | 5 | 4.0 | 5.0 | 4.9 | 8.4 | 1.8 | 2.5 | 3.2 | 5.3 |
| | 6 | 5.4 | 7.0 | 5.4 | 8.8 | 4.2 | 3.3 | 3.7 | 5.5 |
| | Av. | 5.7 | 6.0 | 6.1 | 8.2 | 4.1 | 3.7 | 3.8 | 5.0 |
| Belly | 1 | 11.0 | 10.0 | 14.0 | 17.5 | 7.5 | 4.4 | 7.4 | 14.6 |
| | 2 | 10.1 | 11.5 | 11.6 | 11.2 | 3.4 | 5.4 | 4.7 | 7.4 |
| | 3 | 7.1 | 7.2 | 12.1 | 10.8 | 4.4 | 5.3 | 3.7 | 4.5 |
| | 4 | 8.8 | 9.3 | 12.4 | 13.9 | 3.7 | 3.9 | 3.0 | 6.2 |
| | 5 | 7.4 | 7.4 | 9.3 | 9.1 | 4.4 | 4.9 | 3.8 | 6.2 |
| | 6 | 11.3 | 8.8 | 13.2 | 14.5 | 6.6 | 5.7 | 4.1 | 4.5 |
| | Av. | 9.3 | 9.0 | 12.1 | 12.8 | 5.0 | 4.9 | 4.4 | 7.5 |
| Grand Averages | | 7.5 | | 10.3 | | 4.4 | | 5.4 | |

*Tanning parameter.*—Comparison of fiber aggregate and isotropic hide properties with tanning as the independent parameter is given in Table XIII. The table is divided into three sections to permit scrutiny of properties in the categories of rupture strength, stiffness, and ultimate extensibility.

The correlation, in all three categories, between fiber aggregate and hide properties is very good. In fact, the correlation is almost quantitative, as indicated by the ratio of untanned to tanned properties. It is important to note, however, that the ultimate tenacity for the hides was only about 11% of that of the fiber aggregates. The hide extension to break (ultimate strain)

## TABLE XIII

### CORRELATION OF FIBER AGGREGATE AND HIDE PROPERTIES TANNED VS. UNTANNED SAMPLES

*(Hide properties expressed as isotropic means)*

| Property and Units | | Untanned | Tanned | Ratio |
|---|---|---|---|---|
| Fiber aggregates | Ult. tenacity, g/tex | 31.4 | 23.0 | 1.34 |
| Uniaxial hide tests | Ult. tenacity, g/tex | 3.41 | 2.52 | 1.35 |
| Hide burst strength | kg. (adj.) | 71. | 63. | 1.13 |
| Fiber aggregates | Modulus, g/tex | 149. | 142. | 1.05 |
| Uniaxial hide tests | Modulus, g/tex | 11.6 | 10.5 | 1.10 |
| Biaxial hide tests | Stiffness, kg. (adj.) | 113. | 104. | 1.09 |
| Fiber aggregates | Ult. strain, % | 27.8 | 22.7 | 1.22 |
| Uniaxial hide tests | Ult. strain, % | 41.1 | 30.2 | 1.36 |

was considerably higher than that of the fiber aggregates, for both the untanned and tanned hides; this result might be considered a "necessary condition" for the data to have physical reality.

It was interesting to find, in comparing data for untanned versus tanned samples, that fiber aggregate properties were evidently controlling, as regards hide properties. Yet, the assumption that interaggregate reactions are important is confirmed by the relative magnitudes of ultimate tenacity, modulus, and ultimate strain for the fiber aggregates and the hides, respectively. Apparently, tanning changed the fiber aggregate properties and those of the "interaggregate atmosphere" in approximately equal ratios.

*Hide-to-hide parameter.*—No significant hide-to-hide correlation between properties of fiber aggregates and those of the hides in uniaxial tension was found. Even in the most favorable situation—belly hide properties parallel to the backbone versus fiber aggregates from the belly region—no correlation appeared. It is possible that such a correlation might be found with an increased number of fibers carefully selected from each hide; however, within the limits of accuracy of these experiments, it must be concluded that variations in hide properties observed were probably due to variations in interfiber reactions or differences in fiber aggregate orientation in the various hides.

*Hide region parameter.*—Fiber aggregate data designed to compare the three regions—shoulder, back, and belly—were obtained only with Hide 2. These are given in Table XIV, with comparable uniaxial hide data. It appears that the low ultimate tenacity, low modulus, and high ultimate strain exhibited by the back region of Hide 2 may reflect, in some degree, corresponding fiber aggregate properties. However, it will be recalled that the values

## TABLE XIV

COMPARISON OF UNIAXIAL PROPERTIES OF HIDE 2 AND CONSTITUENT FIBER AGGREGATES

*(Tanned samples; 65% r.h. and 70°F.)*

| Property | Region | Fiber Aggregates | Hide 2: Backbone Direction | Hide 2: Isotropic Average |
|---|---|---|---|---|
| Ult. tenacity, g/tex | Shoulder | 22.7 | 2.61 | 2.34 |
| | Back | 21.6* | 2.32 | 1.94 |
| | Belly | 21.1 | 3.48 | 2.48 |
| Modulus, g/tex | Shoulder | 135 | 15.8 | 12.8 |
| | Back | 111 * | 8.67 | 6.98 |
| | Belly | 140 | 19.2 | 10.9 |
| Ult. strain, % | Shoulder | 22.1 | 18.6 | 20.9 |
| | Back | 27.4* | 29.4 | 31.0 |
| | Belly | 21.1 | 18.5 | 28.0 |

*These values are uncertain in that the average gage length was abnormally low.

of fiber aggregate properties for the back region are rather uncertain. Because of the pronounced anisotropic character of the belly region, it would be hazardous to compare the hide properties of this region with those of the constituent fiber aggregates.

## TABLE XV

COMPARISON OF VARIOUS HIDE PROPERTIES MEASURED PARALLEL AND NORMAL TO BACKBONE

*(Average values for 3 areas of hides 1–6)*

| Property and Units | Untanned Para. | Untanned Norm. | Tanned Para. | Tanned Norm. |
|---|---|---|---|---|
| Uniaxial tests—Ult. tenacity, g/tex | 4.11 | 2.71 | 3.11 | 1.93 |
| Uniaxial tests—Modulus, g/tex | 15.4 | 7.86 | 14.5 | 6.33 |
| Uniaxial tests—Ult. strain, % | 37.2 | 45.2 | 25.0 | 35.3 |
| Biaxial tests—Stiffness, kg/g | 130 | 96 | 141 | 69 |
| Stitch tear tests—Tear strength, kg. (adj.) | 22 | 27 | 29 | 38 |
| Tongue tear tests—Breaking load, kg. (adj.) | 7.1 | 7.8 | 9.2 | 11.3 |
| Tongue tear tests—First tear, kg. (adj.) | 4.3 | 4.4 | 4.7 | 6.1 |

*Anisotropy parameter.*—It was not found possible in the early experiments to select fiber aggregates in anything but a random manner. Thus, there are no data on the variation of fiber aggregate properties in relation to their direction in the hide. With the development of improved techniques of extracting fiber aggregates, this might be possible to achieve, and it is hoped that work of this sort can be done. Lacking such fiber aggregate data, however, it seems of interest to compare various hide data obtained with the applied load parallel and normal to the backbone direction. Such data are summarized in Table XV for the untanned and tanned hides. In accord with earlier remarks, the tear results are inversely related to the ultimate tenacity of the uniaxial tensile tests. Within a group of untanned or tanned samples, the tear strength correlated quite well with uniaxial ultimate strain. However, this was not true in comparing results on untanned versus tanned samples; tear tests appeared to reveal uniquely the benefits of tanning.

## SUMMARY

Significant differences in properties of Steerhides 1–6 were revealed by the uniaxial tensile tests, the burst tests, and the various tear tests. Differences found for the fiber aggregates taken from the six hides were not significant, however. Significant differences in the properties of the shoulder, back, and belly regions of a single hide were also found in the hide tests. Corresponding differences found for the fiber aggregate properties may not have been real.

Excellent correlation between hide and fiber aggregate properties was observed in comparing untanned and tanned samples. Tanning resulted in lower rupture strength, lower modulus, higher extension to rupture, and higher tear strength. Lower values of ultimate tenacity and modulus and higher values of ultimate strain were found in the uniaxial hide tests, as compared to these properties of the corresponding fiber aggregates.

Pronounced anisotropic effects were exhibited by data obtained in uniaxial, biaxial, and tear tests, especially in the case of the belly region. Ultimate tenacity, modulus, and biaxial stiffness were higher in the backbone direction, whereas ultimate strain and tear strength were lower.

On the basis of these findings it may be concluded that the collagen fiber aggregates of these six steerhides were remarkably uniform in properties and that observed variations in hide properties, from hide to hide and within a single hide, resulted mainly from differences in interaggregate reactions and fiber aggregate orientation within the hides. Observed changes in fiber aggregate properties with tanning, paralleling changes in hide properties, indicated, however, that the fiber aggregate properties may play an important, although partial, role in hide and leather performance.

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